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MULTISTABLE ACTUATOR BASED ON MAGNETIC SHAPE MEMORY ALLOY

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Abstract:
Magnetic Shape Memory Alloys (MSMs) are attractive smart materials because they exhibit, at the same time, a large strain (10%) and a short time response (100 µs). In this paper, we propose a novel MSM based actuator exploiting the characteristics of MSMs. This device is a push-pull actuator where two pieces of MSM act in an opposite way. The magnetic fields are created by two magnetic coils supplied by current pulses. The hysteretic behaviour of the MSM permits to keep a stable position when no current is applied and so limits heat losses in the coils. A model of this actuator is proposed and validated by experiments. A precise position feedback control of the actuator is then achieved using a displacement laser sensor.

Keywords: Magnetic Shape Memory Alloy, MSM, actuator, multistable, push-pull

Introduction

In micromechatronics and microrobotics fields, smart materials are actively used. They permit high resolution and distributed actuation. In the range of smart materials, Magnetic Shape Memory Alloys (MSMs) are possible candidates. If a lot of studies already concern them, only few applications use them until now [1,2,3]. MSMs are attractive active materials because of their large strain (about 10%) like the classical shape memory alloys (SMA), but can provide a 100 times shorter time response. The main disadvantages of MSM based actuators are the brittleness of the single-crystal material, the strong magnetic field which has to be applied to obtain sufficient strain and the nonlinear behaviour. The blocking stress (2-3 MPa) is also smaller than this of SMA (150-200 MPa). These drawbacks explain in part the low number of applications. An hysteretic behaviour appears when the material is submitted to stress or magnetic field. Because of this difficulty, most of actuators based on MSM are using an external pre-stress (usually a spring) to obtain a reversible motion. In this paper, we propose a novel MSM based actuator changing the disadvantage of the hysteretic behaviour into an advantage.

Presentation of the multistable actuator

This device is a push-pull actuator: two pieces (A and B) of MSM material act in an opposite way. A picture of this device is given on the Figure 1. The magnetic fields are created by coils and concentrated by ferromagnetic cores. The total length of the device is kept constant by using non-ferromagnetic material. The mobile part of this actuator is in the middle part between the two MSM samples.

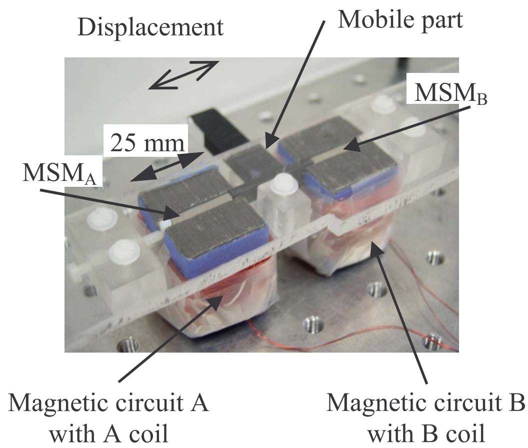

Fig. 1: *The proposed MSM based actuator.*

The principle is the following (see Fig. 2):

(a) At first, MSM_A contains mainly M_1 martensite and MSM_B contains mainly M_2 martensite. The M_1 martensite is larger in the $\vec{e}_x$ direction than the M_2 martensite.
(b) A current pulse is applied in the A coil. It creates a magnetic field through the MSM_A sample in the $\vec{e}_y$ direction. The M_2 martensite fraction increases (the MSM_A expands and the MSM_B contracts) producing a strain in the material. The mobile part moves to the right.
(c) No current is then applied. Due to the hysteretic behaviour of the MSM, the displacement of the mobile part is maintained.

(d) A current pulse is applied in the B coil to obtain a displacement to the left and so on.

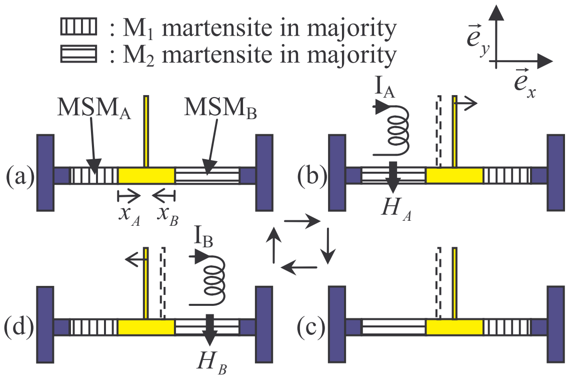

Fig. 2: Principle of the actuator.

During this test, two stable positions of the mobile part are obtained. Furthermore, a stable position depends on the magnitude and the time duration of the current pulses. In fact, an infinity of stable positions can be reached. This actuator is then multistable. Experimental results are shown on the Figure 3. Several voltage pulses are applied in the two coils and the corresponding displacement is measured with a laser sensor. We can see that voltages and then currents are mainly null. In classical MSM actuators (i.e. with spring to obtain reversible motion), the current must be applied continuously. With the multistable actuator, current losses due to the Joule effect into the copper coils are then decreased and this also permits a reduction of the coils size.

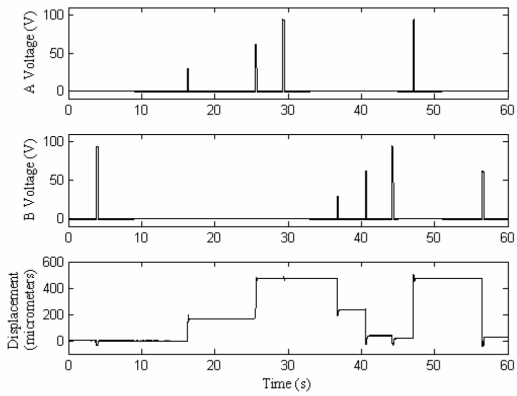

Fig. 3: Open-loop working.

Modelling of the actuator

The complete model of the MSM material is based on irreversible processes thermodynamics. The details are reported in [4]. In the present paper, a simplified model is given.

Firstly, the displacement x_i in the $\vec{e}_x$ direction of the MSM_i sample (i = A or B) can be split into an elastic part x_i^e and a second part corresponding to the displacement due to the reorientation of martensite variants x_i^{tr} :

$$x_i = x_i^e + x_i^{tr} \quad (1)$$

with
$$x_i^e = -\frac{F_i}{k} \quad (2)$$

where F_i is the compressive force in the $\vec{e}_y$ direction applied on MSM_i and k is the elastic coefficient (related to the elastic modulus of the MSM).

Secondly, the reorientation of martensite variants is due to the combination of the mechanical action F_i and the magnetic action $F_i^{mag}(H_i)$ due to the applied magnetic field H_i : a mechanical compression decreases x_i^{tr} , and a magnetic action increases x_i^{tr} . A large hysteretic behaviour is observed for this phenomenon. A simple model of this hysteresis is presented on Figure 4.

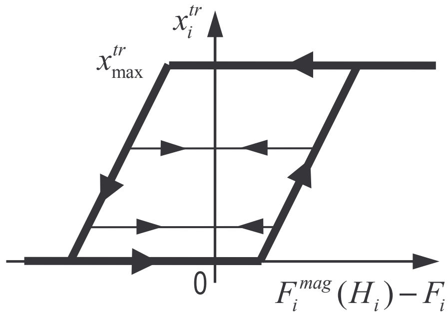

Fig. 4: Hysteresis behaviour due to the martensite reorientation.

Thirdly, we have to consider the design of this actuator. In the static situation and if no external mechanical loading is applied, then the mechanical forces exerted on the two MSMs are equal:

$$F_A = F_B = F \quad (3)$$

The total length of the actuator is constant and fixed to $x_{tr}^{\max}$ value to obtain maximum motion:

$$x_A + x_B = x_O = x_{\max}^{tr} \quad (4)$$

To give a better understanding of the actuator working, we propose to solve equations (3), (4) and hysteresis behaviour of x_A^{tr} and x_B^{tr} using a graphic resolution when a magnetic field is applied on MSM_A.

The graph $x_A = f(F)$ is reported on the Figure 5 for a compressive force (mechanical charge and discharge cycle) with $H_A = 0$. The same graph is reported on the Figure 6 when $H_A = H_A^{max}$.

Due to the equation (4), the graph $x_o - x_B = f(F)$ can be obtained when $H_B = 0$ (see Fig. 7).

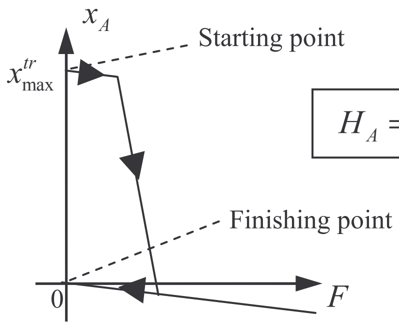

Fig. 5: *Displacement of MSM_A when no magnetic field is applied.*

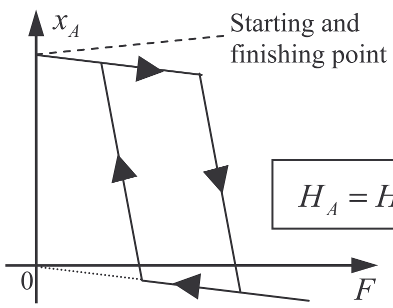

Fig. 6: *Displacement of MSM_A when a magnetic field is applied.*

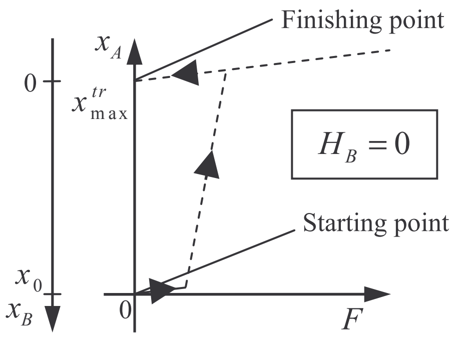

Fig. 7: *Displacement of MSM_B when no magnetic field is applied.*

The working cycle is as follow (steps (a), (b) and (c) of the Figure 2):

(a) The A and B magnetic fields are null (this corresponds to the Figures 5 and 7). The displacements are $x_A = 0$ and $x_B = x_O$. This corresponds to the circle (point 1) on the Figure 8 (where Figures 5 and 7 are superposed).

(b) The B magnetic field is kept null and we increase the A field (see Fig. 6). The circle (representing the x_A and x_B) moves to a second value as represented on the Figure 9 (point 2).

(c) The B field is kept null and we decrease the A field to zero. The circle moves to a third value as represented on the Figure 10 (point 3).

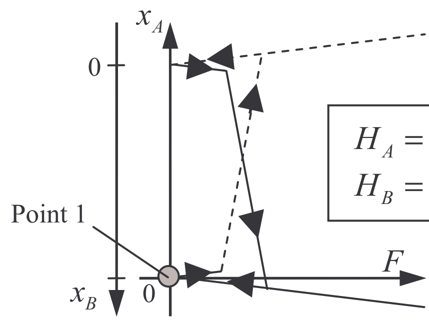

Fig. 8: *First stage of the cycle.*

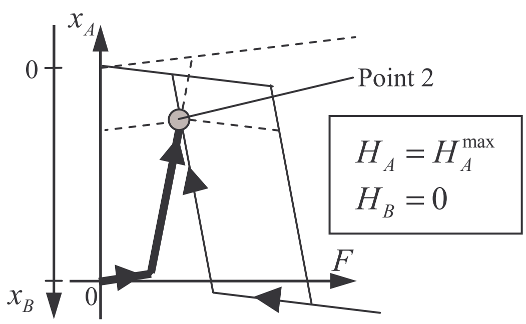

Fig. 9: *Second stage of the cycle.*

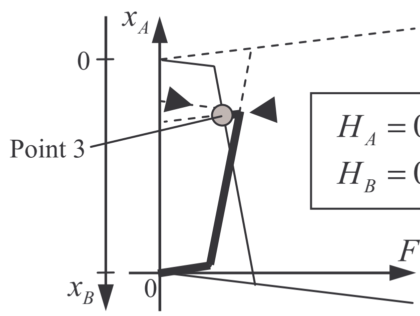

Fig. 10: *Third stage of the cycle.*

This point 3 does not coincide with the point 1 because of the irreversible behaviour of the MSM and does not coincide also to the point 2. Contrary to the representation in Figure 2, a small displacement is observed between the (b) and (c) steps. This behaviour is called "reversible motion". This effect can be interesting for actuation because it is a reversible function of magnetic field unlike the other martensite reorientations.

Simulations and experiments

Model predictions are presented on the Figure 11. It comes from a numerical resolution based on the previous model. The “reversible motions” can be seen. The force is also predicted by the model.

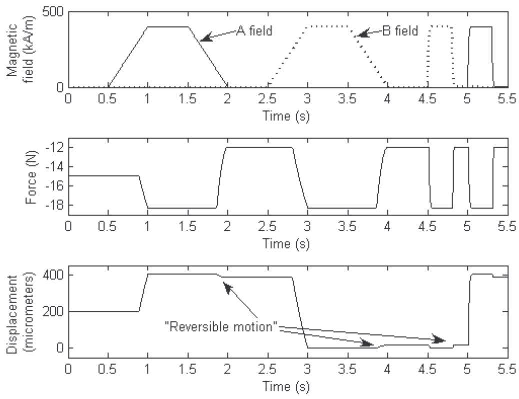

Fig. 11: Results of numerical simulation.

Experiment results are shown on the Figure 12. The displacement is measured with a displacement laser sensor. Good agreements with the model appear when zero or maximum field is applied, but to model precisely the total displacement range, we have to use a more complex model for the hysteretic behaviour. The response time of the device which is given by the current establishment in the coils is about 10 ms.

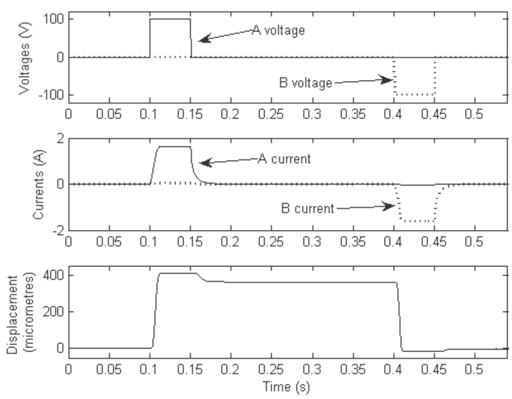

Fig. 12: Experimentations: applied voltages, measured currents, and measured displacement of the actuator.

Performance and Control

A precise control of the actuator is achieved by using a current and position feedback loops associated with PID controllers as depicted on the Figure 13. First results are presented on the Figure 14 for a ramp and for a step set displacement.

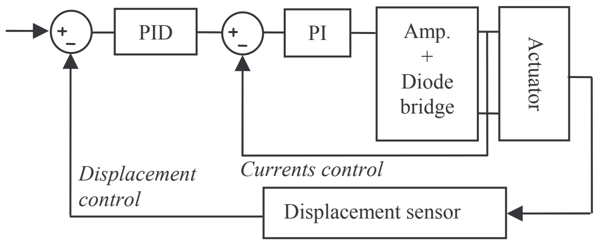

Fig. 13: Control scheme of the actuator.

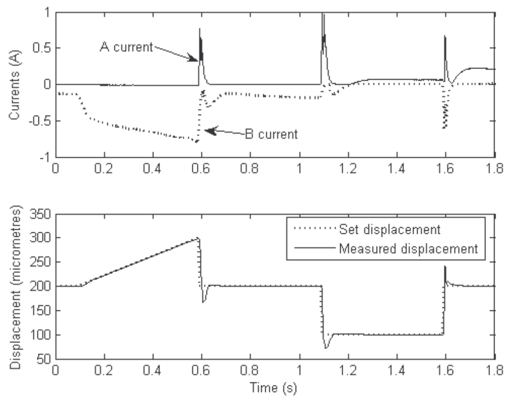

Fig. 14: Experimental results of the control of the device.

Conclusion

A multistable actuator based on MSM has been presented in this paper. A simple model explains the behaviour of the device and a control scheme is performed. We currently work on the completion of the modelling. Based on these futures results, we envisage designing a better feedback control. Finally, this concept of actuator can be miniaturized to obtain a micro-actuator.

References

[1] M. Kohl et al., “Optical scanner based on a NiMnGa thin film microactuator”, *J. Phys. IV France*, 112, pp.1185-1188, 2003

[2] I. Suorsa et al., “Applications of magnetic shape memory actuators”, *8th international conference ACTUATOR 2002*

[3] J. Tellinen et al., “Basic properties of magnetic shape memory actuators”, *8th international conference ACTUATOR 2002*

[4] J. Y. Gauthier et al., “Modeling Rearrangement Process of Martensite Platelets in a Magnetic Shape Memory Alloy Ni2MnGa Single Crystal under Magnetic Field and (or) Stress Action”, *Journal of intelligent Material Systems and Structures* (to appear)